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IMPROVED BAR IMPACT TESTS USING A PHOTONIC DOPPLER VELOCIMETER

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IMPROVED BAR IMPACT TESTS USING A PHOTONIC DOPPLER VELOCIMETER

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Abstract. Bar impact tests, using the techniques described elsewhere in this symposium, were used to measure compressive and tensile strengths of borosilicate glass, soda lime glass, and a glass ceramic. The glass ceramic was 25% crystalline spinel, furnished by Corning Inc. There are two measures of compressive strength: the peak stress that can be transmitted in unconfined compression, and the "steady state" strength. For borosilicate glass and soda lime glass, these values were similar, being about 1.8 and 1.5 GPa, respectively. The glass ceramic (25% spinel) was almost 50% stronger. Tensile failure in the glass and glass ceramic takes places via surface flaws, and thus tensile strength is an extrinsic, as opposed to intrinsic property.

Keywords: Glass, PDV
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INTRODUCTION

The bar impact test has been used for many years for characterizing the compressive strength of brittle materials [1]. Advantages of this technique include use of relatively large specimens, less scatter than is observed with a Hopkinson bar, photograph access to the failure process, and sensitivity to both compressive and tensile strength. Most test configurations involve a cut in the target bar for a gauge plane. Especially for glass, this approach is problematic, because fracture at a gage plane compromises the gage signal, and failure at the gage plane give rise to failure waves [2] that propagate both up and down stream. The best technique for glass-like materials is to measure the free surface velocity of the distal end of the bar. The photonic Doppler velocimeter (PDV) is especially well-suited for this purpose.

EXPERIMENTAL PROCEDURE

Figure 1 is a photograph of the experimental configuration. The target bar is struck by a metal flyer plate launched from a 56-mm diameter air gun. The loading curve of this gun is provided in Figure 2. A crush pin provides a time-of-arrival signal to trigger instrumentation. The bar is held in breakaway plastic mounts. The distal end of the bar is observed with a PDV.

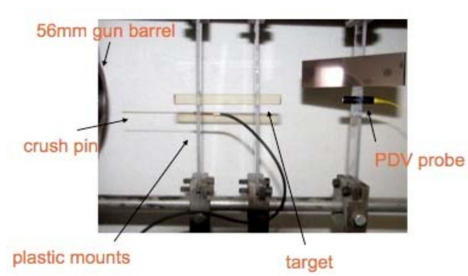

Figure 1. Impact configuration.

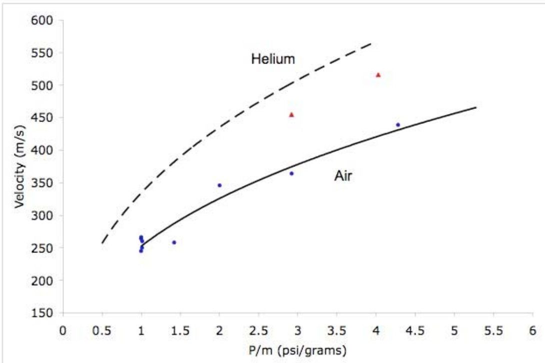

Figure 2. Loading curve for 56 m gun, for air and for helium, also compared with data for 50-mm helium gun from [5].

When ductile materials are used for the target bar, a relatively flat-topped wave is generated with amplitude proportional to the flow stress of the bar. Brittle materials, however, undergo stress relaxation upon failure. The wave interactions for brittle bars are sketched in Figure 3. The first wave propagates at the longitudinal elastic wavespeed. The second elastic wave propagates at the bar wave speed. It is followed by a release wave generated when the impact end fails. Reflection of the tensile pulse may produce a spall signal. The free surface velocity u and stress $\sigma = \rho cu/2$ are connected in the usual way, where ρ is density and c is wavespeed.

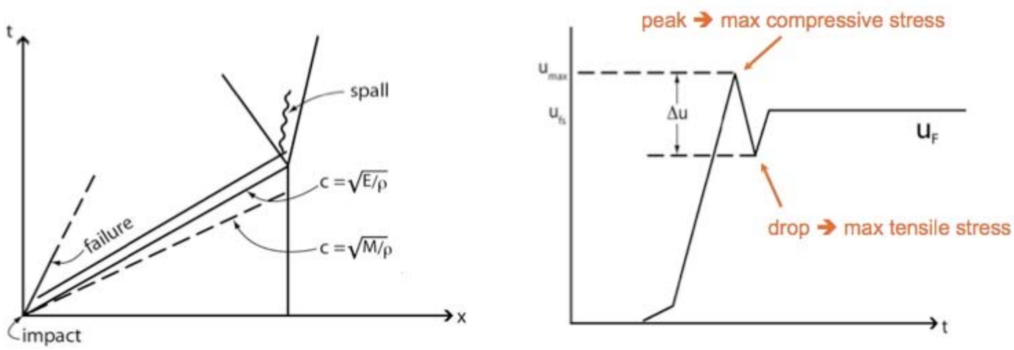

Figure 3. Wave interactions in a brittle bar and consequence free surface velocity record.

There were several variations in experimental techniques. In some tests, a graded density tap supplied by Nguyen [3] was used in an attempt to produce ramp-wave loading in the bar. In all tests with this material, the peak stress was apparently less than in similar tests without the tape. It is speculated that the longer risetime caused by the tape allowed failure to occur before peak stress was achieved.

In early experiments, 3M retro-reflecting tape was applied to the distal end to increase the amplitude of the PDV signal. Indeed the amplitude was greatly increased, allowing the use of non-sacrificial probes. However, direct PDV measurements were made with sacrificial probes in the follow-on experiments out of concern that the tape may have distorted measurements of the peak and minimum stresses (Figure 3, right).

Experiments on the surface finish were also conducted using both frosted and flame polish. Flame polished surface finish gave a crisper signal, but with less amplitude.

PDV MEASUREMENTS

Principles and operational details of the PDV are given in [4,5]. PDV has a number of advantages for the bar-impact application. First, the depth of field is very large. In fact, the projectile could be observed through the 150 mm bar before impact, as shown in Figure 4. Thus, the single instrument measures both the projectile velocity and the free-surface velocity. PDV also has an exceptional dynamic range, being able to follow motion from cm/s to km/s. Virtual experiments can also be conducted with post-processing, trading temporal resolution with velocity (spectral) resolution. Thus, the signal can be processed for maximum precision for times-of-arrival, or for free-surface velocity amplitude. Lastly, the instrument records a velocity spectrum. For example, the breadth of the signal peak in Figure 4 is not believed to be noise. Rather, it is the result of an actual spread in velocity due to disintegration of the bar into a cloud of particles.

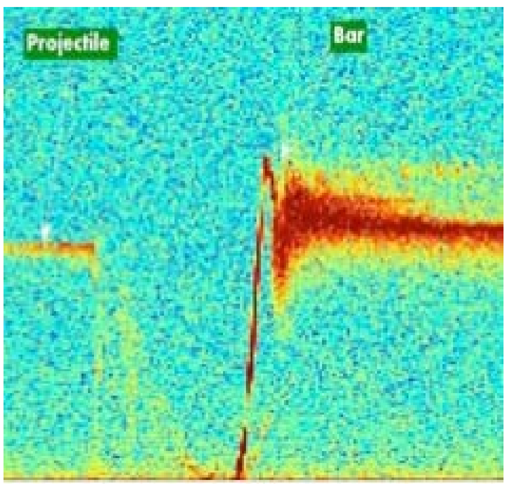

Figure 4. A PDV record showing both the projectile pre-impact and the free surface motion that starts after a wave transit through the bar.

Figure 5 illustrates a PDV record from borosilicate glass. One can resolve both elastic waves. The survival of the longitudinal wave for a bar that is 10 diameters long is surprising and contrary to observations in ceramics [6]. In this example, the peak compressive stress is computed to be 2.2 GPa. There is evidence of a tensile signal, which is bifurcated, suggesting that the bar did not fail uniformly across the section. Then there is a final velocity that is a little less than the peak velocity.

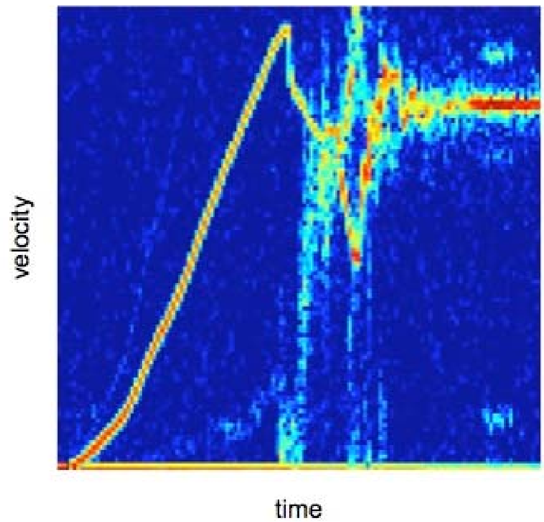

Figure 5. Free surface velocity trace in test 1017.

CONCLUSIONS

1. Sacrificial PDV probes and polished targets are the preferred experimental technique for maximum temporal and velocity resolution.
2. A single PDV probe can be used to measure both impact velocity and bar velocity.
3. Ramp-wave generators decrease the observed peak stress and should not be used for glass-like materials.
4. Retro-reflecting tape may adversely affect velocity resolution.
5. Results from bar impacts are highly reproducible.

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